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# Hybrid Components: Motors and Power Electronics

**Wes Zanardelli, Ph.D., Electrical Engineer**

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# Outline

- **Introduction**
- **Military payoff**
- **Challenges**
- **HE research interests**
  - Motors / generators
  - Power conversion and controls
  - High temperature SiC materials

# Potential benefits and obstacles for Hybrid Tactical Vehicles

## BENEFITS FOR HYBRID

- Improved acceleration & available boost power
- Added Silent watch capability
- Available Silent mobility for short distances
- Improved hull design and enhanced survivability
- Limp home capability through redundancy
- Hybrid architecture facilitates both stationary and on-the-move: On-board & Export power generation
- Potential gain in fuel economy (duty cycle dependent)
- Synergy with pulsed loads (electric weapons and EM armor)
- Flexibility and Improved packaging efficiency
- Added power management capability

## OBSTACLES FOR HYBRID

- Added cost burden (Hybrid Architecture dependent)
- Unproven reliability
- Low temperature components necessitate 2-3 cooling circuits
- Increased total cooling system size and power draw from the engine
- Energy storage limitations
- Maintenance; personnel & soldiers will require additional safety training

# Development Programs

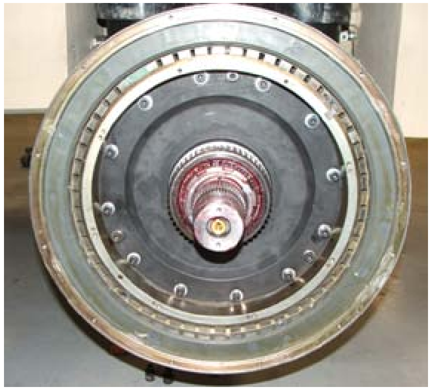


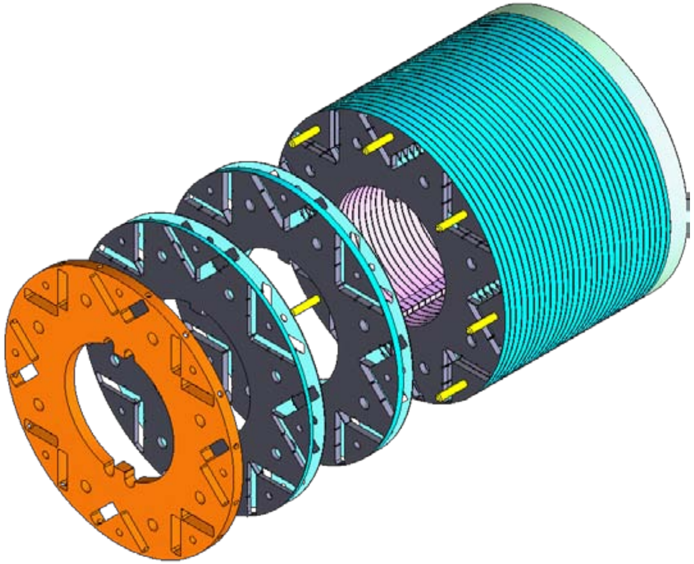
- **Motors / generators**
  - ISG
  - Dual voltage
- **SiC**
- **University Efforts**
  - University of Michigan
  - Michigan State University
- **System Evaluation (SIL)**

# Motors / Motor Controls



- **Motor programs**
  - SPM in-hub wheel motor
  - IPM motor
  - Dual-Voltage ISG
- **Motor/generator control**
  - New in-house initiative
  - O/S development
  - Control algorithm development
  - Hybrid features
  - Optimize efficiency
  - Diagnostics





# Silicon Carbide (SiC) Power Electronics



## Silicon Carbide is a "Game Changing" Technology over Silicon Based Power Electronics:

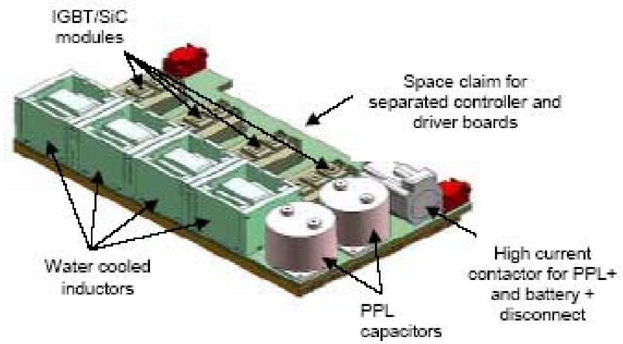
- **Higher operating temperature:**
  - SiC can operate at ≥100ºC versus 70ºC
  - Enables one thermal management cooling loop
- **Higher efficiency:**
  - Switching and conduction characteristics result in approx. 40% reduction in losses for a SiC versus silicon-based power converter *
  - Lower thermal burden reduces energy required to cool system
- **Reduced size and weight:**
  - For 4x higher operating electrical frequency permits:
    - ➢ 50% volume reduction in transformer size
    - ➢ 30% decrease in power converter size
    - ➢ 30% reduction in component weight

* J. D. Scofield, J. N. Merrett (AFRL), J. Richmond, A. Agarwal (CREE), and S. Leslie (Powerex), "Performance and Reliability Characteristics of 1200 V, 100 A, 200°C Half-Bridge SiC MOSFET-JBS Diode Power Modules," International Conference on High Temperature Electronics, May 2010.

# Silicon Carbide (SiC) Power Electronics



- **Challenges**
  - Material development
- **Device/module development**
- **Power converter development**
  - ARRA projects
  - Inverters
  - DC/DC converters
  - SSCB




100 kW Si/Si-C hybrid DC-DC converter

DC/DC Converter

# TARDEC Power Electronics Test Strategy



**Power Electronics Bench Testing**

- Baseline and Test Power Electronics in Controlled Bench Environment.

**Power Electronics HERMIT Testing**

- Integrate Power Electronics into the Hybrid Electric Reconfigurable Moveable Integrated Testbed (HERMIT) for a "Vehicle Like" evaluation.

**Automotive and Environmental Testing**

- Testing power electronic devices for shock and vibration in vehicle platform.

# Backup

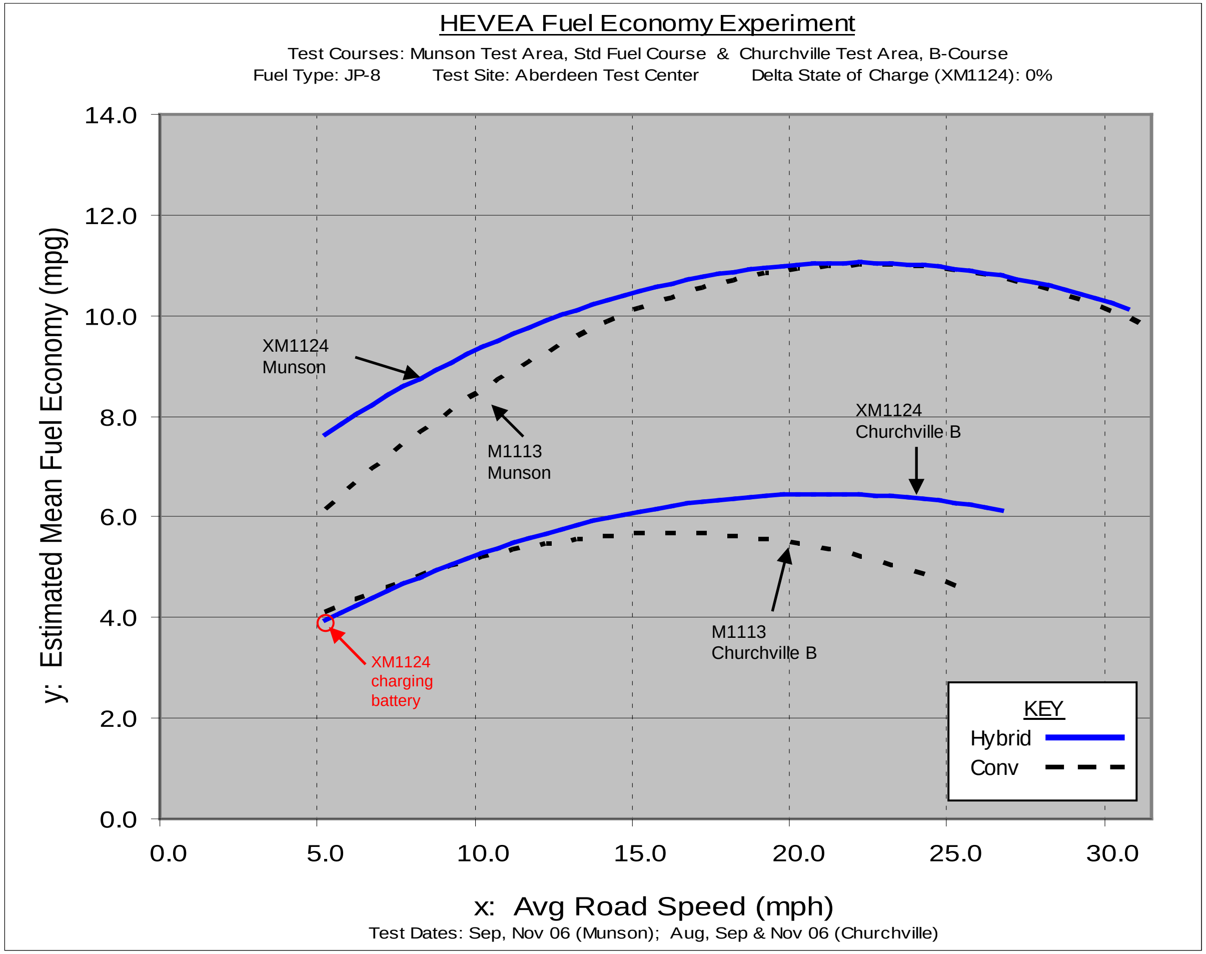
# HEVEA Statistical Models for Conventional & HE HMMWVs -- Munson & Churchville B

**MUNSON (Improved gravel, paved)**:
- Hybrid 4.2% improvement over Conventional (averaged over common speed range of 5.1-30.7 mph)

**CHURCHVILLE B (Hilly cross-country)**:
-Hybrid 10.9% improvement over Conventional (averaged over common speed range of 5.1-25.0 mph)

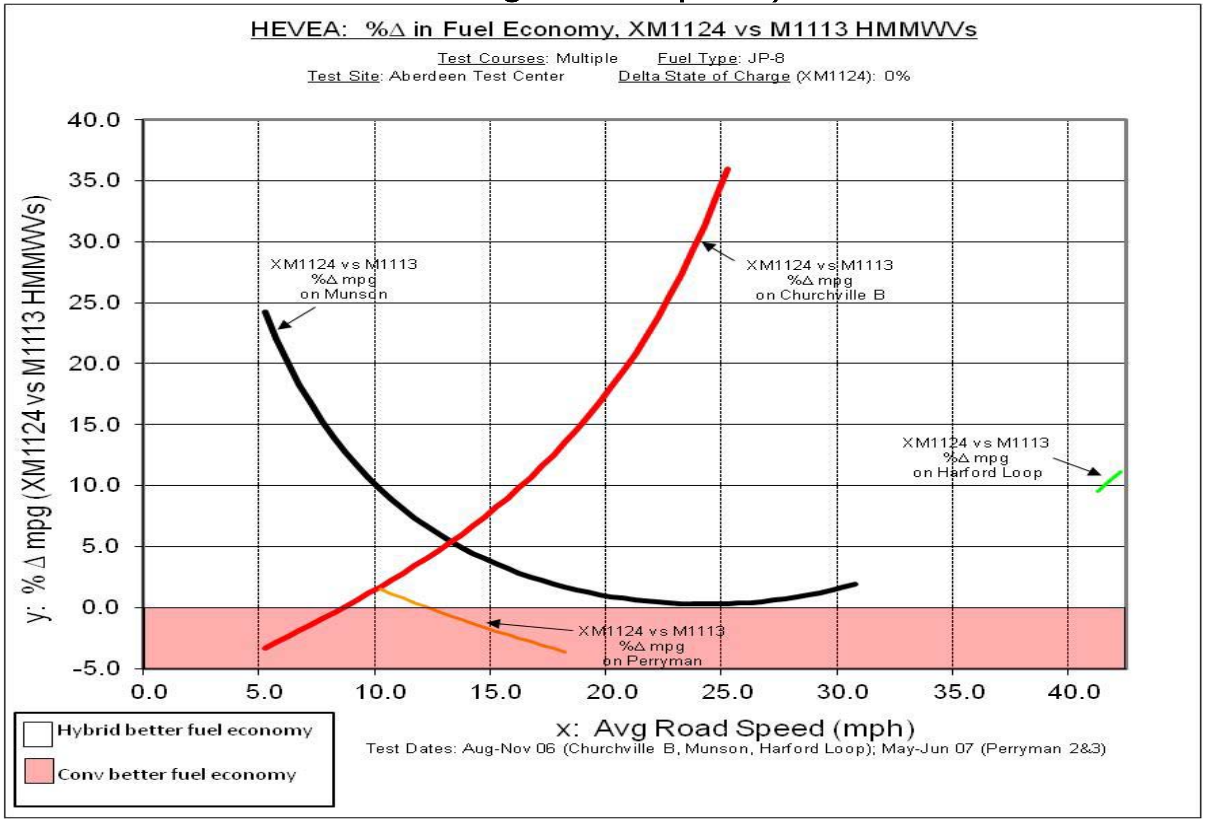
| Vehicle & Course | Statistical Model ($\Delta SOC = 0$) |
|---|---|
| **MUNSON:** | |
| XM1124 | $y = 5.332 + 0.524x - 0.012x^2 - 0.222\ \Delta SOC$ |
| M1113 | $y = 2.974 + 0.717x - 0.016x^2$ |
| **CHURCHVILLE B:** | |
| XM1124 | $y = 2.109 + 0.417x - 0.010x^2 - 0.031\ \Delta SOC$ |
| M1113 | $y = 2.321 + 0.417x - 0.013x^2$ |

| Key Test Vehicle Characteristics | M1113 | XM1124 |
|---|---|---|
| Type | Conv Mech | Series Hybrid |
| Company | AM Genl | AM Genl |
| Test wt (lbs) | 11,500 | 11,500 |
| Engine | 6.5L Turbo 190 hp | 2.2L Turbo 139 hp |
| Battery capacity | 1 kWh Pb Acid | 15 kWh Li ion |
| On-bd pwr (DC) | 5.6 kW | 2.8 kW |
| Export pwr (AC) | N/A | 30 kW |




Notes:
-The hybrid HMMWV provides a significant amount of silent watch capability
-HE does better on Munson up to 20 mph because the efficiency gain in the electric drive system is higher at low speeds; at >20 mph, there is an increased cooling load on the hybrid, which allows the mechanical drive to be more efficient. The hybrid does better up to the first 5 mph because there is a great deal of loss due to the hydrokinetic transmission in the conventional vehicle that the hybrid vehicle does not experience. After the torque converter locks up, conventional drivetrain efficiency improves significantly.
-The HE system demonstrates more benefit on Churchville B due to the hilly terrain. The system captures energy on downhill runs (re-gen) and can use the energy on uphill runs. At low speeds the hybrid electric is using all of the power from the battery and engine to make it up the hill, then using fuel and the engine to charge the battery. At higher speeds, the hybrid system reaches steady state and becomes more efficient.

# Fuel Economy Percent Comparisons (% Δ Mean FE vs. Avg Road Speed)



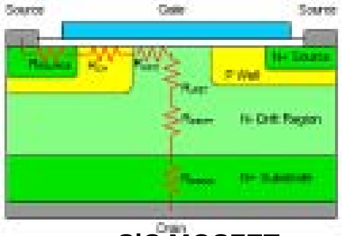

Interpretation of Results. Based on the given statistical models of the test data over the range of speeds, the hybrid HMMWV showed, on the average, the following % improvement in mean fuel economy over the conventional HMMWV: 4.2% on Munson over the common interval of 5.1 - 30.7 mph; 10.9% on Churchville B over the common interval of 5.1 – 25.0 mph.

## Military Vehicles Require Very High Torque and Power

- System integration and Packaging
  - Power densities of components
    - Motors, generators, energy storage
    - Power electronics

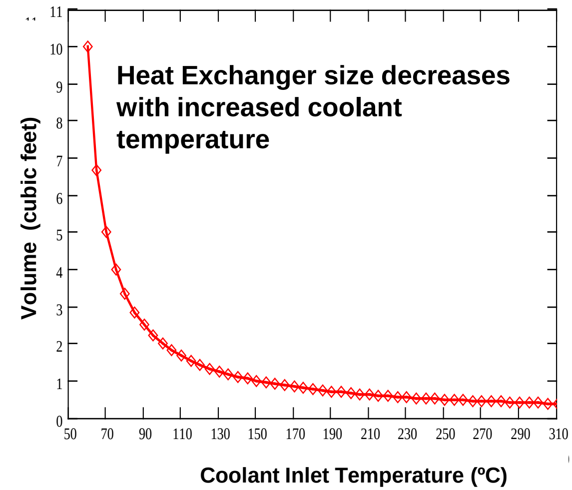
High Power density motor

High temperature power electronics



SiC MOSFET

- Thermal management
  - Low operating temperature
    - Large space claims
    - High power demand from the engine/generator




- Silent Watch requirement
  - Energy storage shortfalls
  - Control strategy and limited power budget

Li-Ion Battery Pack

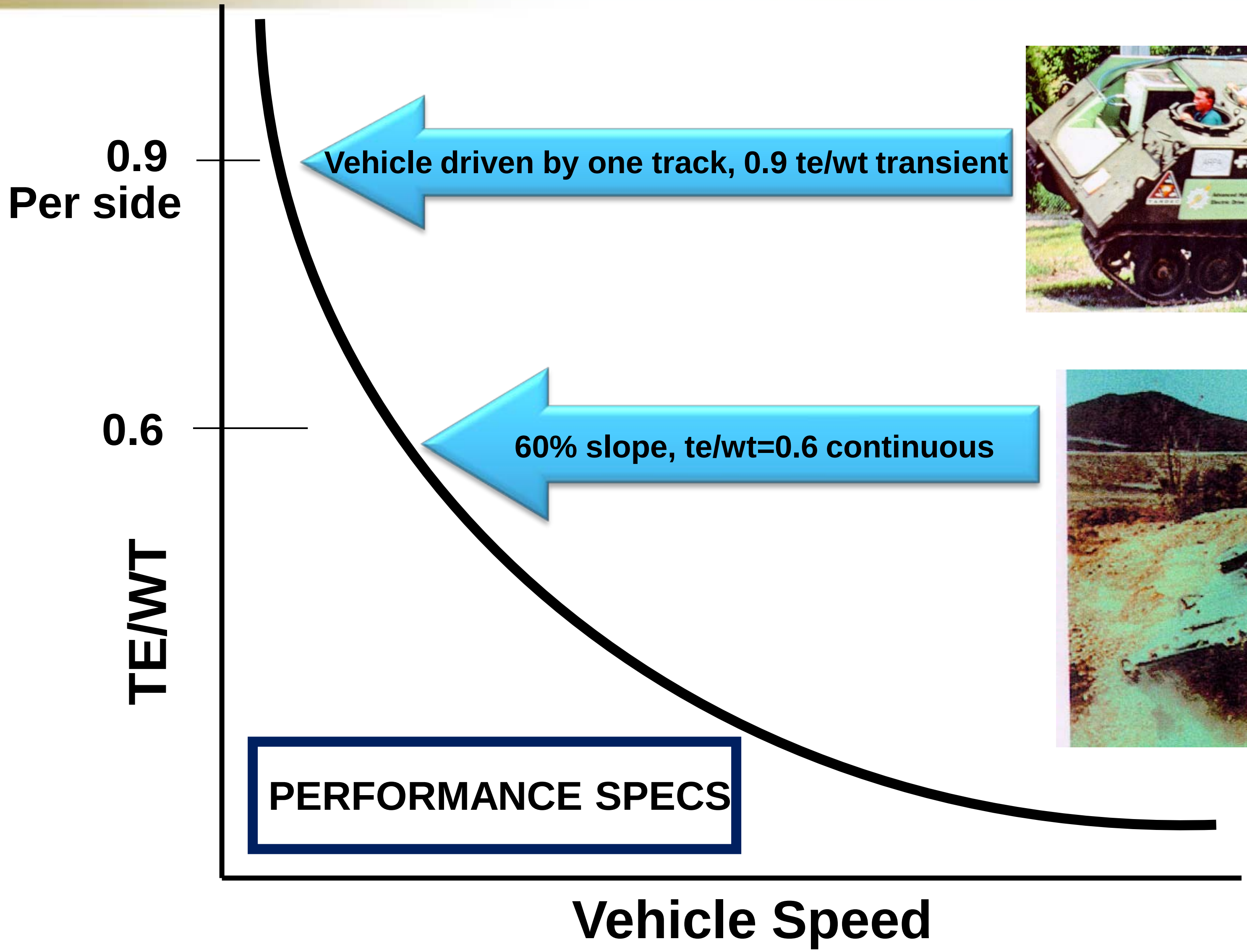
- Onboard Exportable power
  - Clean power for Tactical Operating Centers (TOC)
  - Power supply from mobile platforms for other applications

C4ISR TOC

- Reliability and safety assessment requires additional SIL and vehicle testing

- High development cost

# Military Environment




# Hybrid vs. Non-Hybrid Component Comparison

## Hybrid Version – JLTV

**Major Components**

1. Prime Mover-Diesel Engine
2. Generator and Generator Inverter
3. Traction motor(s) and Inverter(s)
4. DC-DC Convertor
5. Integrated Starter Generator algorithm
6. Energy Storage System and BMS
7. Low Temperature cooling circuit
8. Multi cooling circuits
9. Power Management Modules
10. EMI Filtration devices

## Non-Hybrid Version - JLTV

**Common Components**

1. Prime Mover-Diesel Engine
2. Generator and Generator Inverter
3. DC-DC Convertor
4. Integrated Starter Generator algorithm
5. Energy Storage System and BMS
6. Low Temperature cooling circuit
7. Multi cooling circuits
8. EMI Filtration devices
9. Added Software/Controls
10. Mechanical path (Drivetrain)

- If the Non-hybrid version were to meet all of the requirements including silent watch the architecture would include the mass majority of the components required for hybrid.
- The components that are known to be unreliable would be apparent in both configurations.
- Incorporating all of these components into current JLTV is one step short of a mild hybrid